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STUDIES ON NEW GUINEA MOTHS. 1. INTRODUCTION (LEPIDOPTERA)

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Abstract.—This is the first in a series of papers providing taxonomic data in support of ecological and biogeographic studies of moths in New Guinea. The primary study is an extensive inventory of the caterpillar fauna of a lowland rainforest site near Madang, Papua New Guinea, from 1994–2001. The inventory focused on the Lepidoptera community on 71 woody plant species representing 45 genera and 23 families. During the study, 46,457 caterpillars representing 585 species were sampled, with 19,660 caterpillars representing 441 species reared to adults. This introductory contribution is intended to provide background on the project, including descriptions of the study site, sampling methods, and taxonomic methods.

Key Words: Malesia, Papua New Guinea, Lepidoptera, biodiversity, rearing, community ecology

A very large portion of tropical biodiversity consists of herbivorous insects, and among them, Lepidoptera are among the most amenable to study. To better understand the structure and maintenance of tropical biodiversity, we undertook a series of related inventories of Lepidoptera in New Guinea. Our most extensive data set is an inventory of the caterpillar fauna of lowland rainforests near Madang, Papua New Guinea, from 1994–2001. Our ecological analyses focus on the Lepidoptera community on 71 woody plant species representing 45 genera and 23 families near Madang. Of these species, 69 are native, while 2 species of *Piper* are not native. But for taxonomic purposes we have evaluated specimens accumulated more broadly, including the material resulting from a study focused on 10 woody plant species conducted near Wau, Papua New Guinea, in 1992 and 1993 (Basset 1996, Basset et al. 1996). This paper represents the first in a series of papers providing taxonomic documentation in support of the broader studies, and is intended to provide general background, including descriptions of the study site, sampling methods, and taxonomic methods.

During 2002, we sampled an additional 19 woody plant species near Madang, bringing the total sampling universe to 90 species representing 58 genera and 32 families. The sampling effort per plant was reduced according to the guidelines in Novotny et al. (2002c). The insects from these surveys are still being analyzed. At the time of this writing, the Madang study is being expanded to include montane sites and a series of lowland sites, and material from these studies will be discussed and described in later papers in this series. Sampling began at our first montane site in June 2001 in primary and secondary forests and partially deforested landscape around Mu Village near Kundiawa town in Chimbu Province (145°02′E, 6°05′S, 1,800 m).

Materials and Methods

Madang Study Area

The study area is situated in Madang Province, Papua New Guinea, extending from the coast to the slopes of the Adelbert Mountains. Average annual rainfall in this area is 3,558 mm, with a moderate dry season from July to September; mean air temperature is 26.5 °C (McAlpine et al. 1983). The area is covered with species-rich evergreen rainforest (152 species of woody plants with diameter at breast height ≥5 cm per hectare; Laidlaw et al., in press). Fieldwork was concentrated in primary and secondary lowland forests near Baitabag, Ohu, and Mis villages, and in a coastal area near Riwo Village (145°41–8′E, 5°08–14′S, ca. 0–200 m). Specific localities are Baitabag (145°47′E, 5°08′S, ca. 100 m), Ohu (145°41′E, 5°14′S, ca. 200 m), Mis (145°47′E. 5°11′S, ca. 50 m), Riwo Village (145°48′E. 5°09′S, 0 m).

Madang Plant Sampling

Seventy-one species of trees and shrubs from 45 genera and 23 families (see appendix), including 15 species of *Ficus* and 1 species of *Artocarpus* (Moraceae), 6 species of *Macaranga* and 9 species representing 9 other genera of Euphorbiaceae, 4 species of *Psychotria* and 12 species representing 12 other genera of Rubiaceae, 3 species of *Syzigium* (Myrtaceae), 3 species of *Piper* (Piperaceae) and 18 species representing 18 other families of flowering plants, were selected for the study of their associated caterpillars. Moraceae, Euphorbiaceae, and Rubiaceae, which were studied in detail, are important components of lowland rainforest flora in the Madang area and elsewhere in New Guinea (Oatham and Beehler 1998). The five genera represented by multiple species are among the most important ones in local rainforests, with combined diversity of 579 species in New Guinea (Höft 1992). This selection of families includes all main lineages of flowering plants, viz. gymnosperms, monocotyledons, basal eudicots, euasterids and eurosids (APG 1998). Further, locally common plants from all main habitats within the study area, including early and late stages of forest succession as well as riverine and seashore habitats, were represented (Leps et al. 2001).

Plants were identified by Wayne Takeuchi at Lae Herbarium and many of them were subsequently verified by the best available international specialists. Plant vouchers are deposited in Bishop Museum (BISH), Rijksherbarium (L), Lae Herbarium (LAE) and Smithsonian Institution (US) (herbarium acronyms follow Holmgren et al. 1990).

Madang Insect Sampling and Rearing

All externally feeding caterpillars (Lepidoptera), including leafrollers and leaftiers, were collected by hand from foliage. During each sampling occasion, a collector spent one day walking throughout the study area searching the foliage of the target tree species for caterpillars. The sampling included only more accessible branches, i.e., those which could be reached easily by climbing or reached from the ground. Numerous trees from various parts of the study area were sampled during each sampling occasion. The number of tree inspections, that is, a particular tree sampled at a particular time, was recorded, as well as the approximate area of the foliage sampled. Each tree species was sampled continuously for the period of at least one year between July 1994 and December 2001. Sampling effort was equal for all plant species and amounted to 1,500 m^2 of foliage area examined per species, while the number of tree inspections exceeded 1,000 per plant species. This sampling effort represented approximately 2,000 person-days of fieldwork. In the laboratory, each caterpillar was provided with fresh leaves of the plant species from which it was collected, and was reared to an adult whenever possible. Only the specimens that fed were considered in the analyses. Caterpillars and adults were assigned to morphospecies. Morphospecies were assigned seven character codes as permanent identifiers—four letters representing the family and three digits—which remain unchanged even if the field identification of the family was incorrect.

Our sampling of the 71 plant species produced 46,457 caterpillars representing 585 species, with 19,660 caterpillars representing 441 species reared to adults. Most of the field activities were carried out by parataxonomists, as described in Basset et al. (2000). The numbers reported in our analytical papers are often lower, because various analyses included only a subset of the plant species or were adjusted to equalize sample size per host plant.

In addition to the basic locality data and adult morphospecies code, standard labels including caterpillar morphospecies, host plant name, host plant abbreviation, and specimen number, were affixed to each specimen. The caterpillar morphospecies code begins with "CAT" and is used on specimens after 1995. The original host plant identification on the label sometimes has changed with further study, so should be used with care. For this reason, beginning in 1996, the labels include a three letter host plant abbreviation that does not change with subsequent identifications. Individual specimen numbers are assigned to all specimens reared to adults. Early specimens bear numbers in Bishop Museum database series, while later specimens bear numbers in Smithsonian database series—the use of Bishop Museum and Smithsonian on the labels provides a unique specimen number and does not in itself identify ownership of the specimen (e.g., Thompson 1994).

All data regarding specimens, their rearing status, morphospecies numbers, and identifications, along with images of insects and hosts, are recorded in a custom Access database, described in Basset et al. (2000). Background data and images are available at www.nmnh.si.edu/new_guinea.

Our taxonomic studies also incorporate material reared near Wau, Papua New Guinea by Yves Basset and assistants during the precursor to the Madang project in 1992–1993 (Basset et al. 1996). Morphospecies numbers for these specimens are distinguished by beginning with "LE." The plants from that study were identified by Robert Höft and vouchers are deposited at LAE and L.

Insect Identification

In the laboratory, the morphospecies concepts were confirmed by disection of genitalia (Clarke 1941, Robinson 1976) and examination of other characters. Identifications were made using relevant literature, but especially by comparison to the collections of Smithsonian National Museum of Natural History, Washington (USNM), Bishop Museum, Honolulu (BPBM), and especially the rich historic collections of The Natural History Museum, London (BMNH), as well as less frequent comparisons to collections of Australian National Insect Collection, Canberra (ANIC) and Nationaal Natuurhistorisch Museum, Leiden (RMNH), and types in other collections. Because most of the types of New Guinea moths are at BMNH, it has been the critical resource, and we are especially indebted to their staff, as well as research associates J.D. Holloway and M. Shaffer, for unlimited access.

General taxonomic context is provided by Holloway et al. (2001), although we follow Kristensen (1998) in recognizing Crambidae as a family. For macrolepidoptera, the ongoing series "Moths of Borneo" (Holloway 1984–present) provides a vital foundation. For pyraloids and microlepidoptera, Robinson et al. (1994) and Diakonoff (1952–1955) provide a general context. Nielsen et al. (1996) provide a taxonomic framework for the Australian fauna that has been very helpful. Gressitt and Szent-Ivany (1968) provide a bibliography of Lepidoptera systematics literature for New Guinea, now updated by us and available online at www.nmnh.si.edu/new_guinea.

Taxonomic characters, and definitions of genera and species, follow those in general use in Lepidoptera (e.g., Miller 1994), as well as specialist literature as available. The reviews of many families in "Moths of Borneo" have been especially important in guiding generic and specific concepts. Because our immediate need is identification of the reared species, we often verified identifications by dissection of type specimens, but have not reviewed the variability across the entire geographical range of the species. Cytochrome oxidase I (COI) sequences, DNA barcodes of Hebert et al. (2003), follow the protocols outlined in Hebert et al. (2003). The primary set of Lepidoptera vouchers are deposited in USNM, with representatives in the National Agricultural Research Institute (Port Moresby), BPBM, and other collections as appropriate.

Other Material

The historic collections of USNM, BPBM, and especially BMNH (Frodin and Gressitt 1982) provided the context for the Madang collections. USNM collections include material collected in Irian Jaya by Syuti Issiki May–August 1936, and in Papua New Guinea by Gary Hevel in December 1976, Scott Miller and Pamela Miller in July–August 1983, and Vitor Becker in September–October 1992. The BMNH collection is especially rich because of a series of excellent collectors sent to New Guinea by Walter Rothschild for the Tring Museum (Rothschild 1983), and also includes many vouchers from agricultural and forestry projects (e.g., Bigger 1988).

In addition to the general collections at BPBM (Frodin and Gressitt 1982) and material collected by Larry Orsak around Wau and Madang in the early 1990s, there is an important collection of Geometroidea assembled by the late J. J. H. Szent-Ivany. From 1968 to 1971, and again in 1974, Szent-Ivany collected Geometroidea at light and by rearing around Wau Ecology Institute, Papua New Guinea. He assembled a collection of some 300 species (listed in Gressitt and Nadkarni 1978: 83–88) which is now at BPBM. Szent-Ivany identified these during an extended visit to BMNH. Unfortunately, little of his rearing data have been published, and many of the reared specimens remain cryptically labelled.

Discussion

A prerequisite to investigation of the ecology of species-rich insect taxa in diverse habitats such as lowland tropical rain forests is a large sample size. Our sampling generated data on a scale that has rarely been achieved in the tropics (see Janzen 1988, Janzen and Gauld 1997, Janzen 2003 for a similar exercise in Costa Rica). Our data are now being used for a series of taxonomic (e.g., Holloway and Miller 2003) and ecological analyses (e.g., Novotny et al. 2002a, b, c). Some of the ecological conclusions are reviewed below.

Individual host-plant species sustained from 9 to 75 (median 25) species of caterpillars. Caterpillar communities were strongly dominated by a single or few species. The single most common species typically represented 52% of individuals and 50% of biomass while the five most common species represented >80% of individuals and biomass in the entire community (Novotny et al. 2002c). In addition to these dominants, each community included a large number of very rare species (Novotny and Basset 2000). Despite significant sampling effort, the species accumulation curves for individual host plant species did not approach an asymptote which suggests that the total species richness of caterpillar communities was not sampled (Novotny et al. 2002c).

Caterpillars were mostly specialized to a single plant family, and within families to a single genus, while capable of feeding on multiple congeneric hosts (Novotny et al. 2002b). Only 15% of the caterpillar species feeding on *Ficus*, *Macaranga*, and *Psychotria* strongly preferred a single host species (Novotny et al. 2002a), but even among these species, none was strictly monophagous. Thus, it is conceivable that no, or very few, genuinely monophagous caterpillars feed on speciose plant genera in rain forests. A large overlap among caterpillar communities on congeneric plants means that the total number of species feeding on speciose plant genera is relatively small, in comparison with their size. These differences, in combination with low host specificity of herbivores with respect to congeneric plants, suggest that the average overlap among herbivore communities on tropical trees may be higher than on temperate trees (Novotny et al. 2002a).

Caterpillar communities were not seasonal, and the majority of species were present almost continuously throughout the year (Novotny et al. 2002c). Community composition was also constant spatially over distances <20 km (Novotny et al. 2002c). The dominance of caterpillar communities by a small number of species, which also exhibited low spatial and temporal variability, permitted robust and reliable estimates of community composition and between-community similarity from small samples, typically <300 individuals per host plant. In contrast, even considerably larger samples were not sufficient for estimates of community species richness (Novotny et al. 2002c).

The analyses produced from these data show the importance of large samples collected over multiple years in understanding the structure of tropical insect communities. These large samples have only been logistically feasible with a team approach, utilizing the skills of parataxonomists, ecologists, and systematists.

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Appendix

Full list of the 90 species of plants sampled near Madang, alphabetically by family. The three letter code is used on insect specimen labels and allows positive association with the correct name in case the plant identification has changed from the original identification. Novotny et al. (2002b) provided a phylogeny for 45 of these species.

Family	Name	Abr
Agavaceae	*Cordyline terminalis* P. Beauv.	COR
Agavaceae	*Dracaena angustifolia* Roxb.	DRA
Apocynaceae	*Tabernaemontana aurantica* Gaud.	TAB
Araliaceae	*Osmoxylon sessiliflorum* (Lauterb.) W R. Philipson	OSM
Arecaceae	*Hydriastele microspadix* (Becc.) Burret	ARE
Bignoniaceae	*Spathodea campanulata* (L.) Kunth.	SPA
Caesalpiniaceae	*Maniltoa* cf. *plurijuga* Merrill & Perry	MAN
Euphorbiaceae	*Breynia cernua* (Poir.) Muell. Arg.	BRE
Euphorbiaceae	*Codiaeum ludovicianum* Airy Shaw	COD
Euphorbiaceae	*Endospermum labios* Schodde	END
Euphorbiaceae	*Excoecaria agallocha* L.	EXC
Euphorbiaceae	*Homalanthus novoguineensis* (Warb.) K. Schum.	HOM
Euphorbiaceae	*Macaranga aleuritoides* F. Muell.	MAA
Euphorbiaceae	*Macaranga bifoveata* J.J. Smith	MAP
Euphorbiaceae	*Macaranga brachytricha* Airy Shaw	MAF
Euphorbiaceae	*Macaranga densiflora* Warb.	MAD
Euphorbiaceae	*Macaranga novoguineensis* J.J. Smith	MAU
Euphorbiaceae	*Macaranga quadriglandulosa* Warb.	MAQ
Euphorbiaceae	*Mallotus mollissimus* (Geisel.) Airy Shaw	MAL
Euphorbiaceae	*Melanolepis multiglandulosa* (Reinw. ex Bl.) Reichb.f. & Zoll.	MEL
Euphorbiaceae	*Phyllanthus lamprophyllus* Muell. Arg.	PHY
Euphorbiaceae	*Pimelodendron amboinicum* Hassk.	PIM
Euphorbiaceae	*Eupomatia laurina* R. Br.	EUP
Fabaceae	*Pterocarpus indicus* Willd.	PTE
Flacourtiaceae	*Casearia erythrocarpa* Sleum.	CAS
Gnetaceae	*Gnetum gnemon* L.	GNE
Heliconiaceae	*Heliconia papuana* W.J. Kress	HEL
Lecythidaceae	*Barringtonia* sp.	BAR
Leeaceae	*Leea indica* Merrill	LEE
Loganiaceae	*Neuburgia corynocarpa* (A.Gray) Leenh.	NEU
Malvaceae	*Hibiscus tiliaceus* L.	HIB
Malvaceae	*Sterculia schumanniana* (Lauterb.) Mildbr.	STR
Malvaceae	*Trichospermum pleiostigma* (F. Muell.) Kostermans	TRI
Meliaceae	*Aglaia* cf. *cucullata* (Roxb.) Pellegr.	AGL
Monimiaceae	*Kibara* cf. *coriacea* Hook.f. & Thoms.	STG
Moraceae	*Artocarpus communis* J.R. et G. Forst.	ART
Moraceae	*Ficus bernaysii* King	BER
Moraceae	*Ficus botryocarpa* Miq.	BOT
Moraceae	*Ficus conocephalifolia* Ridley	CON
Moraceae	*Ficus copiosa* Steud.	COP
Moraceae	*Ficus dammaropsis* Diels	DAM
Moraceae	*Ficus erythrosperma* Miq.	ERY
Moraceae	*Ficus gul* K. Schum. & Laut.	GUL
Moraceae	*Ficus hispidioides* S. Moore	HIS
Moraceae	*Ficus microcarpa* L.	MIC
Moraceae	*Ficus mollior* F. Meull. ex Benth.	MOL
Moraceae	*Ficus nodosa* Teysm. & Binn.	NOD
Moraceae	*Ficus pachyrrhachis* K. Schum. & Laut.	PAR
Moraceae	*Ficus phaeosyce* Laut. & K. Schum.	PHA

APPENDIX

Continued.

Family	Name	Abr.
Moraceae	*Ficus pungens* Reinw. ex Blume	PUN
Moraceae	*Ficus septica* Burm.	SEP
Moraceae	*Ficus subtrinervia* Laut. & K. Schum. (= *F. pachystemon* Warb.)	PAS
Moraceae	*Ficus ternatana* Miq.	TER
Moraceae	*Ficus tinctoria* Forst.	TIN
Moraceae	*Ficus trachypison* K. Schum.	TRA
Moraceae	*Ficus variegata* Blume	VAR
Moraceae	*Ficus wassa* Roxb.	WAS
Myristicaceae	*Myristica* cf. *sepicana* D.B. Foreman	MYL
Myrtaceae	*Syzigium longipes* (Warb.) Merrill & Perry	SSW
Myrtaceae	*Syzygium* sp. 1	SRS
Myrtaceae	*Syzygium* sp. 2	SRB
Piperaceae	*Piper aduncum* L.	PAD
Piperaceae	*Piper macropiper* Pennant	PMV
Piperaceae	*Piper umbellatum* L.	PUB
Rubiaceae	*Amaracarpus nymanii* Valeton	AMA
Rubiaceae	*Dolicholobium oxylobum* K. Schum.	DOL
Rubiaceae	*Gardenia hansemannii* K. Schum.	GAR
Rubiaceae	*Morinda bracteata* Roxb.	MOR
Rubiaceae	*Mussaenda scratchleyi* Wernh.	MUS
Rubiaceae	*Nauclea orientalis* (L.) L.	SAR
Rubiaceae	*Neonaclea clemensii* Merrill & Perry	NEO
Rubiaceae	*Pavetta platyclada* Lauterb. & K. Schum.	PAV
Rubiaceae	*Psychotria leptothyrsa* Miquel	PSF
Rubiaceae	*Psychotria micralabastra* (Laut. & K. Schum.) Val.	PSM
Rubiaceae	*Psychotria micrococca* (Laut. & K. Schum.) Val.	PSS
Rubiaceae	*Psychotria ramuensis* Sohmer	PSL
Rubiaceae	*Randia schumanniana* Merrill & Perry	MEN
Rubiaceae	*Tarenna buruensis* (Miq.) Val.	TAR
Rubiaceae	*Timonius timon* (Spreng.) Merrill	TIT
Rubiaceae	*Versteegia cauliflora* (K. Schum. & Laut.)	VER
Rutaceae	*Lunasia amara* Blanco	LUN
Sapindaceae	*Pometia pinnata* Forster	POM
Sapotaceae	*Pouteria* sp.	POU
Sterculiaceae	*Kleinhovia hospita* L.	KLE
Ulmaceae	*Celtis philippensis* Blanco	CEL
Urticaceae	*Leucosyke capitellata* (Poir.) Wedd.	LEU
Verbenaceae	*Geunsia farinosa* Blume	GEU
Verbenaceae	*Premna obtusifolia* R.Br.	PRE
Verbenaceae	*Teijsmanniodendron* sp.	TEI
Zingiberaceae	*Hornstedtia scottiana* (F. Muell.) K. Schum.	HOR